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Assessment of Diesel Particulate Control Particle Size Measurements

Southern Research Inst.
Birmingham, AL

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

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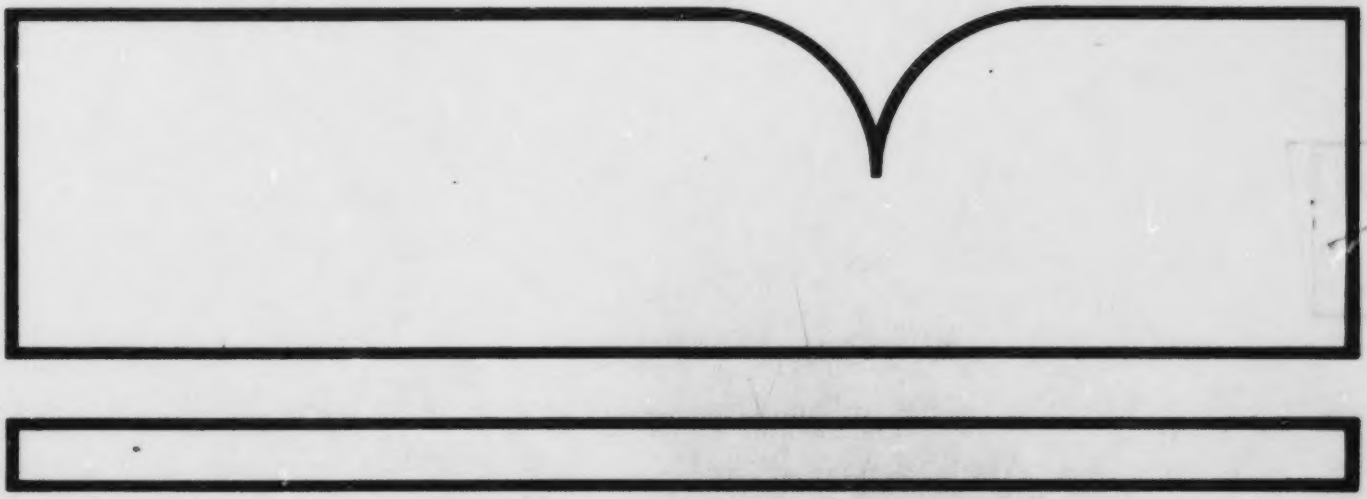

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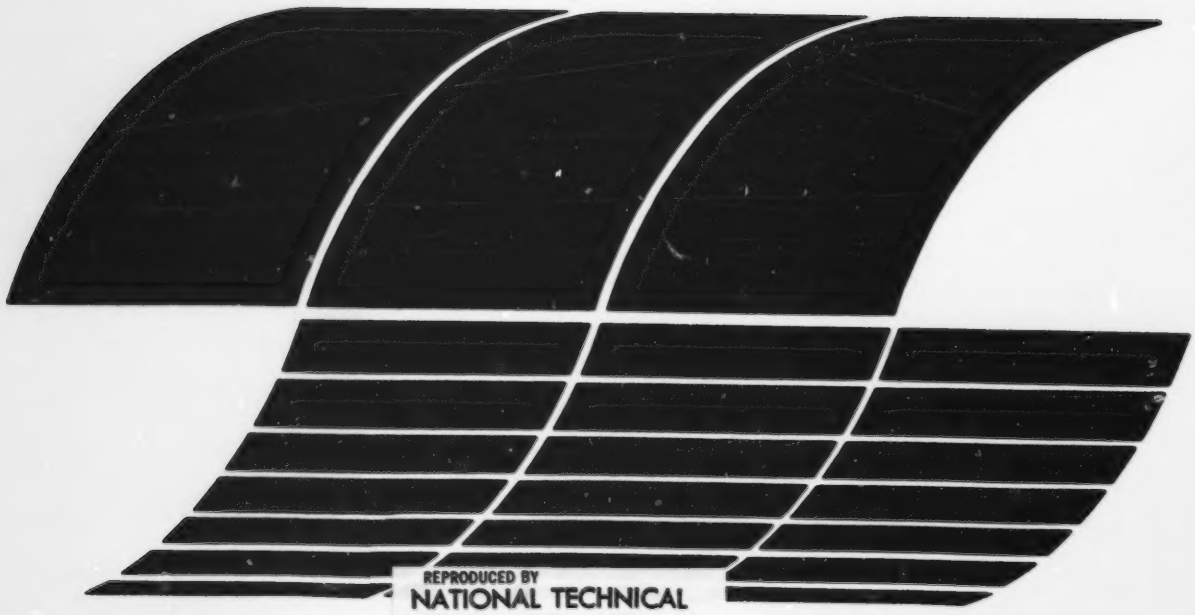

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16. ABSTRACT The report gives results of tests on an Oldsmobile 98 diesel automobile to obtain data on parameters typical of a light duty vehicle. Data are presented for operations under four simulated driving conditions. (The increasing appearance of the diesel engine on the passenger car market has led to concern over particulate emissions (smoke) from these engines. Possible control strategies involving particulate collection in the hot exhaust stream requires knowledge of the concentrations and size distributions of the particulate matter at exhaust conditions.) Typical particulate concentrations at exhaust line conditions for the 350 CID diesel engine were found to be about 50 mg/Ncm. Aerodynamic mass median diameters were about 0.3 to 0.5 micrometers with the larger median diameters from higher engine speed/load conditions under steady state operation. Test results are qualitatively similar in size distribution to those found by other investigators in measurements of emissions from heavy duty diesel engines insofar as the impactor data are concerned. Additional particle size and composition data are required under conditions where the engine speed/load can be maintained at a constant value while the exhaust temperature is varied. This data would determine the suitability of particle collection at exhaust gas temperatures and would help define collection device cooling needs.

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Exhaust Gases	Particulate	11G
Dust		21B
Smoke		07D
Aerosols		21G
Diesel Engines		13F
Automobiles		

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Assessment of Diesel Particulate Control: Particle Size Measurements

by

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ABSTRACT

The increasing appearance of the diesel engine on the passenger car market has led to concern over particulate emissions (smoke) from these engines. Possible control strategies involving particulate collection in the hot exhaust stream requires knowledge of the concentrations and size distributions of the particulate matter at exhaust conditions. Tests were performed on an Oldsmobile 98 diesel automobile to obtain data on these parameters typical of a light duty vehicle. Data are presented for operations under four simulated driving conditions.

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SECTION 1

INTRODUCTION

The federally mandated fuel economy standards for passenger automobiles have resulted in considerable impetus being given to the introduction of substantial numbers of diesel powered automobiles into the passenger car fleet. Unfortunately, the diesel engine has a much higher level of combustion by-products than the spark ignition gasoline engine (by factors of 30 to 50 in particulate emissions). The diesel particulate emissions are primarily carbonaceous, but 10 percent to 50 percent by weight of the material is adsorbed higher molecular weight organics, a significant portion of which may be polycyclic aromatics.[1] Preliminary results of Ames microbial mutagenicity bioassay tests have indicated the possibility that these particulates may be carcinogenic.

Possible methods for reducing diesel particulate emissions are combustion modification or the use of aftertreatment devices in the exhaust gas stream to collect and/or render the material innocuous. Such treatment may be mandatory if the emissions do prove to represent a significant carcinogenic risk. Selection of candidate aftertreatment devices requires knowledge of the chemical and physical properties of the particles. These include particle morphology, particle size distribution, bulk densities

of the collected material, and particulate mass concentration and emission rates in the exhaust gas stream. Because the organic fraction of the particles appears to be adsorbed on the surfaces of graphitic carbon base particles, the temperature history of the gas stream may be important. If the sorption process takes place at elevated temperatures, then collection of the particulate at the normal, relatively hot, exhaust gas temperatures may be sufficient. However, if the sorption takes place only during and after cooling of the exhaust stream to near ambient conditions, hot particle collection will not result in the removal of the organic fraction.

The data presented in the following chapters represent the first of a planned series of experiments to characterize the exhaust emissions from the point of view of aftertreatment exhaust gas cleanup and to collect samples for bioassays to determine whether the biological effects of particles collected at exhaust line temperatures are the same as those collected after dilution and cooling by ambient air.

SECTION 2

TEST CONDITIONS

The exhaust samples were obtained at the U.S. Environmental Protection Agency facility located at Research Triangle Park, North Carolina, from November 27 through December 1, 1978. The source of particulate was a 1979 Oldsmobile 88 with a 350 cubic inch displacement diesel engine which was operated on a Burke E. Porter No. 1059 Chassis Dynamometer. The dynamometer was programmed to emulate the Clayton roadload curve for waterbrake dynamometers which are used for vehicle certification. Test conditions included the 13 minute Fuel Economy Test (FET) combined city-highway test cycle, 97 kmph highway cruise, 56 kmph highway cruise, and 56 kmph no load conditions. However, the engine operating conditions, the particulate sampling methods, and the exhaust temperature conditions were all different from those required by EPA for vehicle certification and the test results should not be compared to those acquired by official certification methods and conditions.

The vehicle operating conditions and experimental setup were selected to provide samples collected at elevated exhaust gas temperatures for the same engine cycle as the very large (10 kg) sample collected for bioassay work. This 10 kg bioassay sample was collected during the FET test cycle using a standard "constant volume" automatic dilution tunnel. The hot samples collected were to be used for Ames tests to provide some indication

of the relative mutagenicity of material collected at the exhaust line temperatures and material collected after cooling and dilution. This information is intended to provide some insight into whether hot collection of the particles will remove the carcinogenic component of the exhaust.

Sampling and measurement methods included Andersen cascade impactors, conventional filtration techniques followed by condensers and organic sorbent traps using XAD2 rosin, optical single particle counters, and an electrical aerosol analyzer. All samples were taken directly from a modified exhaust pipe which was run out from under the chassis and down the passenger side of the automobile to permit access to the exhaust stream. Figure 1 is a diagrammatic sketch of the layout of the exhaust system and measurement instrumentation during the tests.

Andersen Model III cascade impactors with glass fiber impaction substrates and backup filters were used to obtain total particulate loadings and particle size distributions on a mass basis over the size range from about 0.4 μmA to 5 μmA. The impactors, which were operated in an oven, were close-coupled to the exhaust pipe. During runs at a steady engine load (56 kmph and 97 kmph), the oven was maintained at the same temperature as the exhaust gas temperature at the sampling point. During the 13 minute FET cycle testing, the impactors and ovens were maintained at about the average exhaust gas temperature for the cycle, 175°C.

In addition to the cascade impactors, a Thermosystems Model

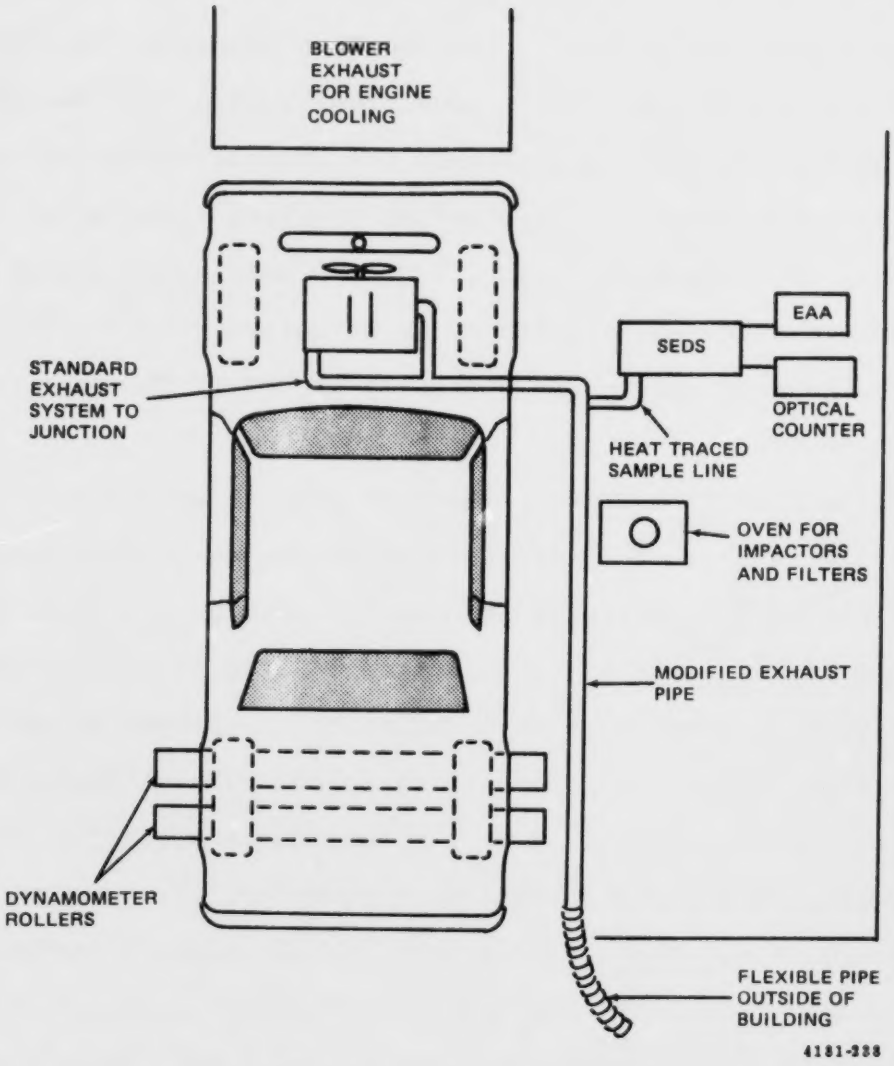

Figure 1. Modified exhaust pipe and test equipment layout for diesel emission testing.

3030 Electrical Aerosol Analyzer (EAA) was used to determine concentrations and size distributions of particles in the size range of 0.01 μm to 0.5 μm. Particle concentrations ranging from 0.3 μm to 2.5 μm were monitored using a Royco Model 225 optical particle counter. The Southern Research Institute SEDS III sample extraction, conditioning, and dilution system was used as an interface between the exhaust system and the EAA and particle counter. This system provides a mechanism for the removal of condensible vapors from the sample gas stream at elevated temperatures followed by quantitative dilution to particle concentrations within the operating ranges of the measurement instruments.

The initial intent of the test program was to collect particle samples at a number of points between the exhaust manifold and the tailpipe in order to provide specimens collected over a range of temperatures and engine loads. These data were to have provided information on changes in particle size distribution and composition as the exhaust gases were cooled. Unfortunately, time limitations in preparing for and performing the tests precluded carrying out the proposed plan. Although it was found that a considerable swing in exhaust gas temperature did occur with changes in engine load, it proved impossible to differentiate between load/speed induced and temperature induced concentration and composition changes in the data obtained during this test.

SECTION 3

TEST RESULTS

Overall particulate loadings, engine gas flows, and sampling temperatures for the cascade impactor samples are given in Table I. Particle size distributions for the various conditions are given in Figures 2, 3, 4, and 5. Each figure in this series contains a plot of cumulative percentage smaller than the indicated diameter versus diameter from the impactor data alone and that obtained by integrating the distributions from the electrical aerosol analyzer up to 0.5 μm and continuing the integration from 0.5 μm to 10 μm with the impactor data. A particle density of 1.0 g/cm^3 was assumed for the integrations of the EAA data. The overall size distributions from 0.01 μm to 10 μm obtained in this fashion agree very well with those obtained from the impactors alone.

The variability in particulate concentrations through the FET cycle is illustrated in Figure 6. This shows particle concentrations versus time in three particle size intervals through several test cycles. These data were obtained using the optical particle counter.

Figure 7 is an electron micrograph of diesel particulate collected on the backup filter of one of the Andersen impactors. These figures clearly show the branched, chainlike

TABLE I. RESULTS OF CASCADE IMPACTOR SAMPLING

Operating mode	Average exhaust volume flowrate (m^3/s)	Average exhaust temperature at sampling location (°C)	Particulate loading (mg/NCM)	Aerodynamic mass median particle diameter (μmA)
FET cycle	0.051	177	68	0.26
97 kmph	0.057	218	55	0.54
56 kmph (with load)	0.033	149	45	0.46
56 kmph (no load)	(Not Available)	129	39	0.33

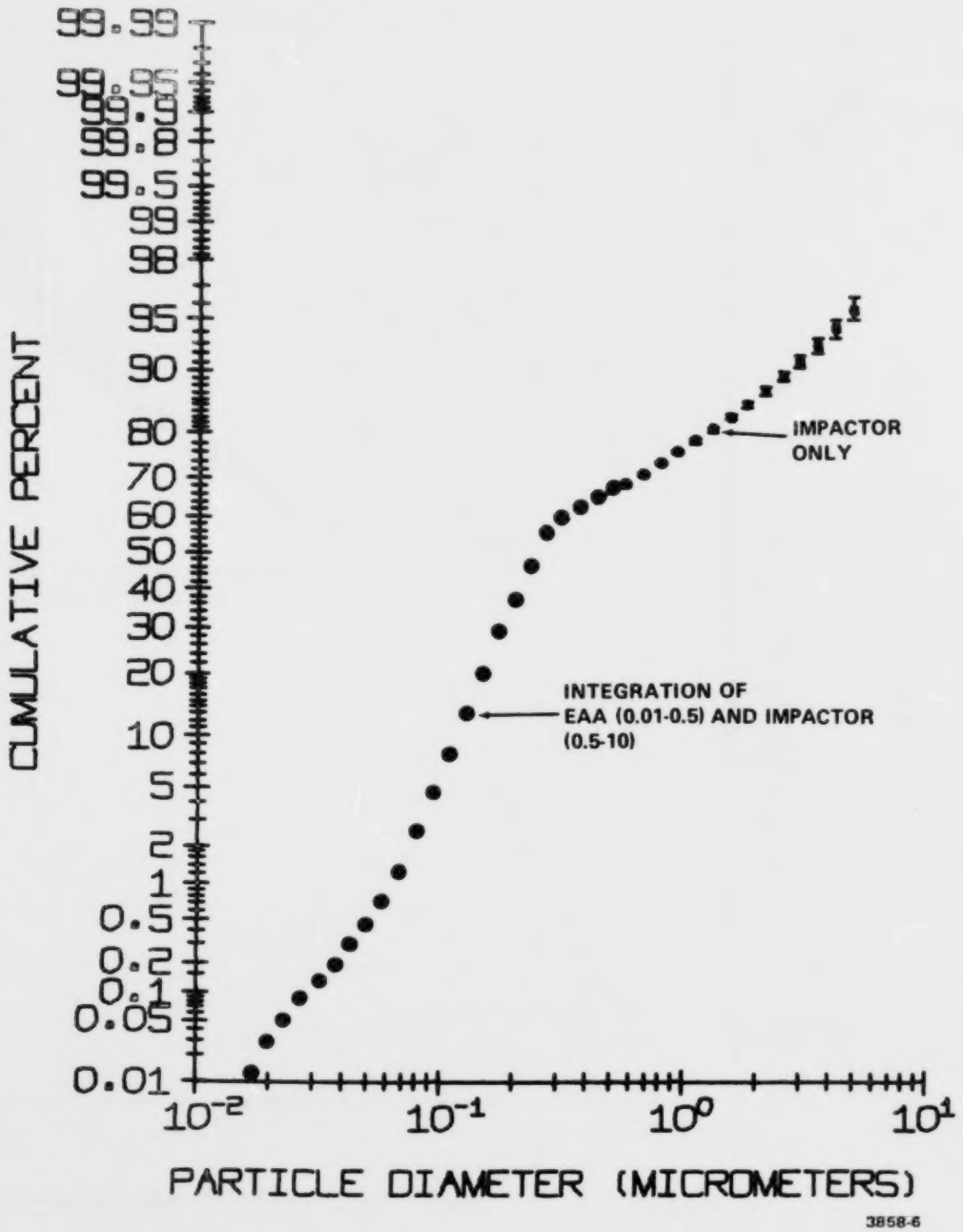

Figure 2. Particle size distribution for FET-cycle.

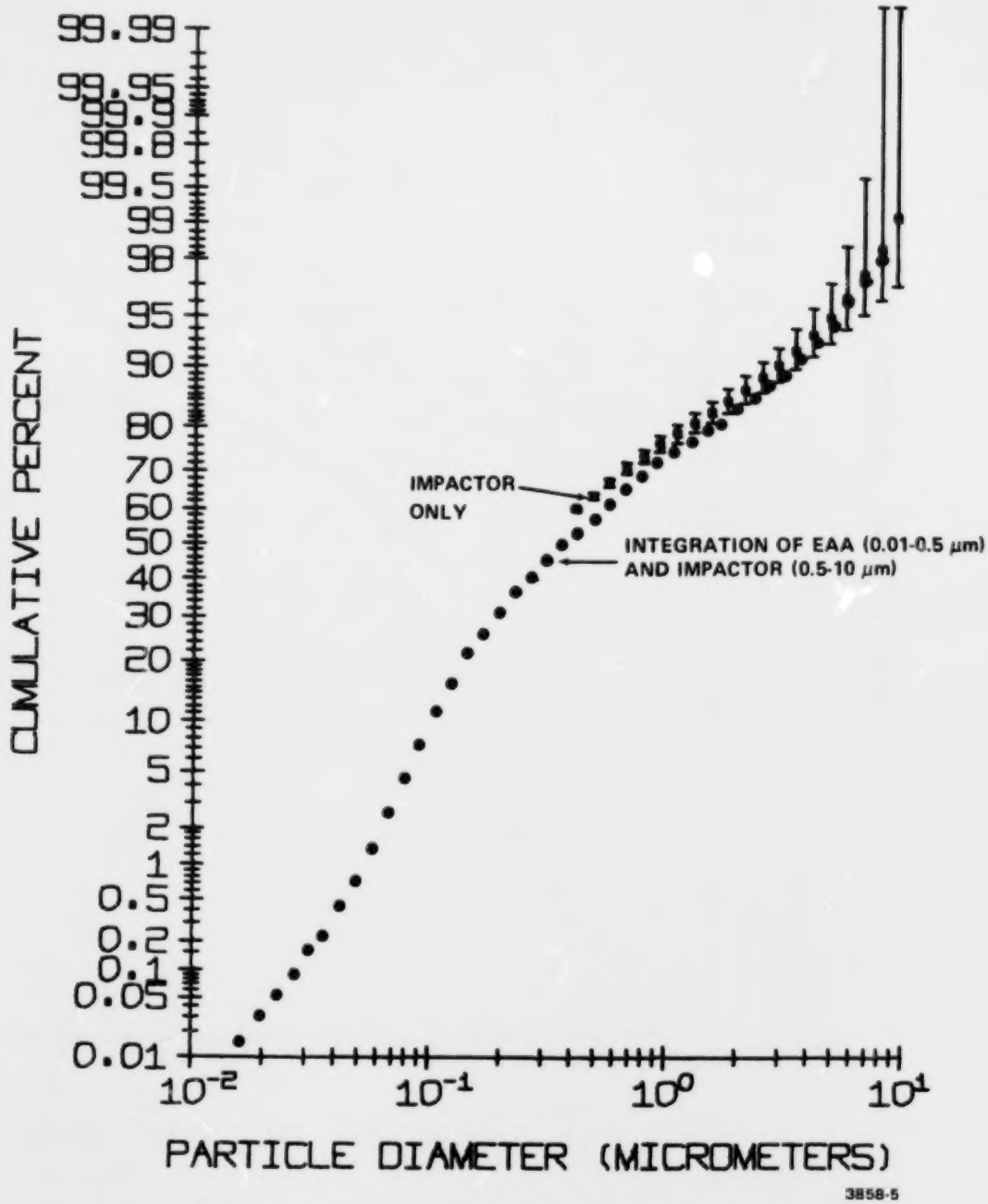

Figure 3. Particle size distribution for 56 kmph no load condition.

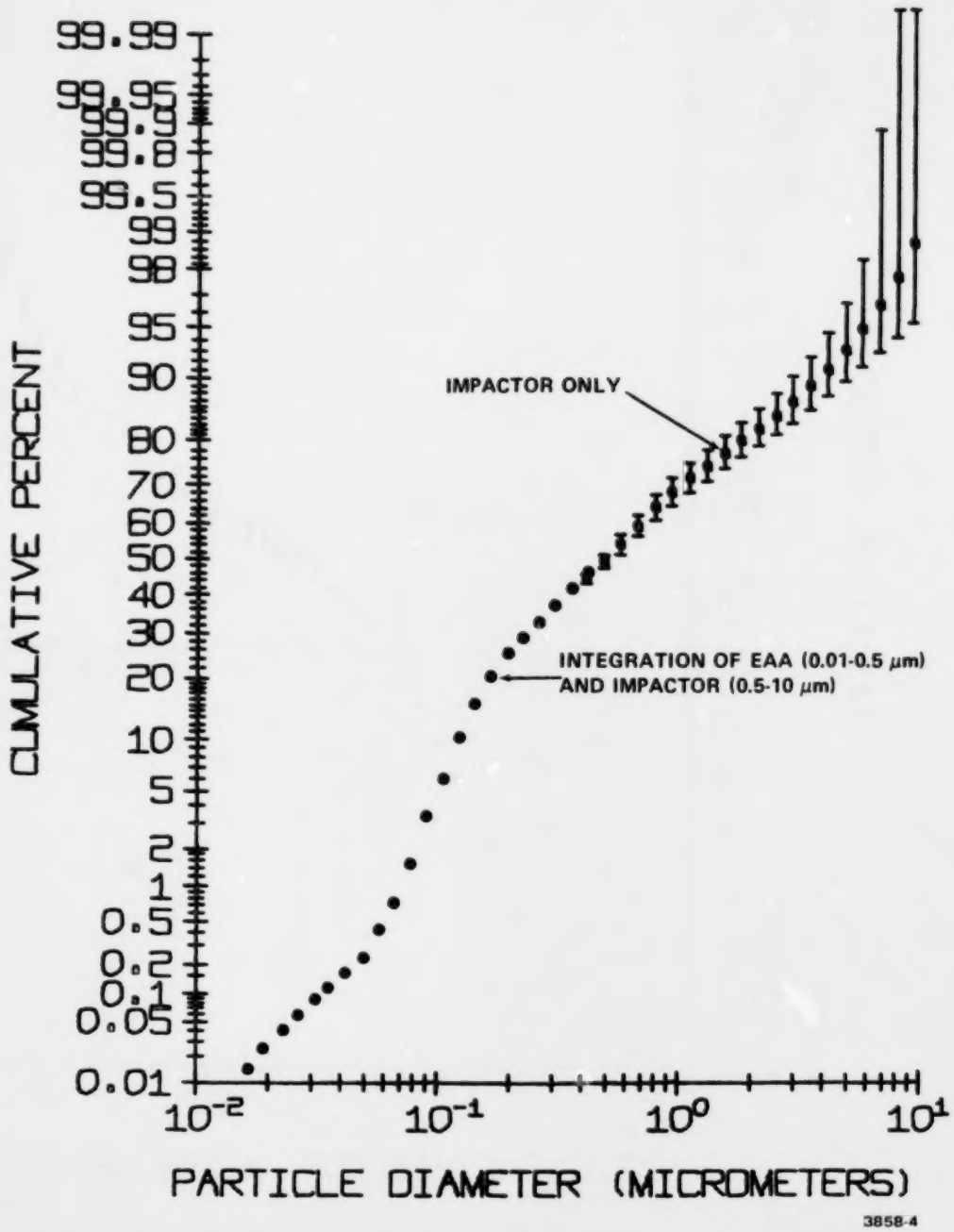

Figure 4. Particle size distribution for 56 kmph with load condition.

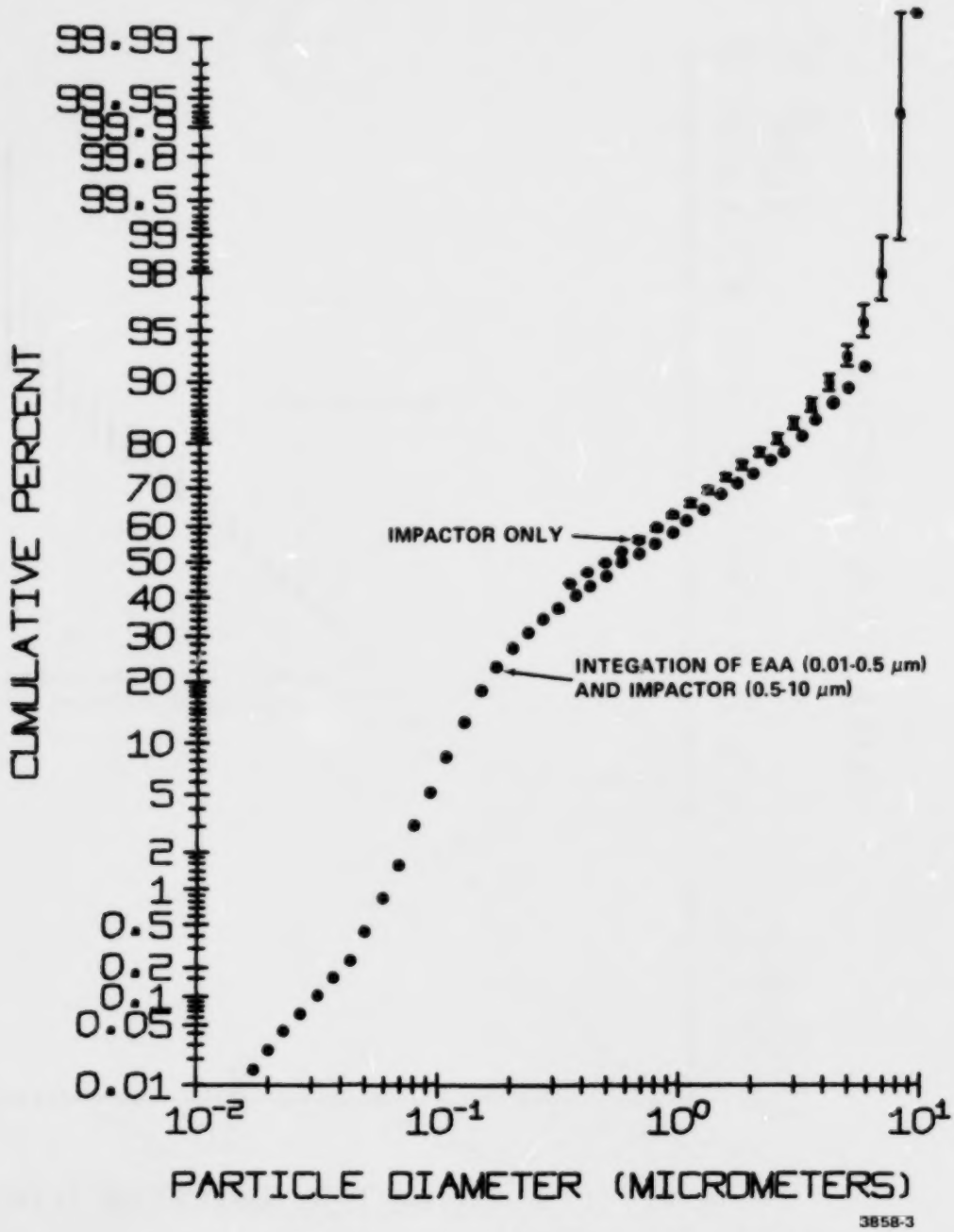

Figure 5. Particle size distribution for 97 kmph condition.

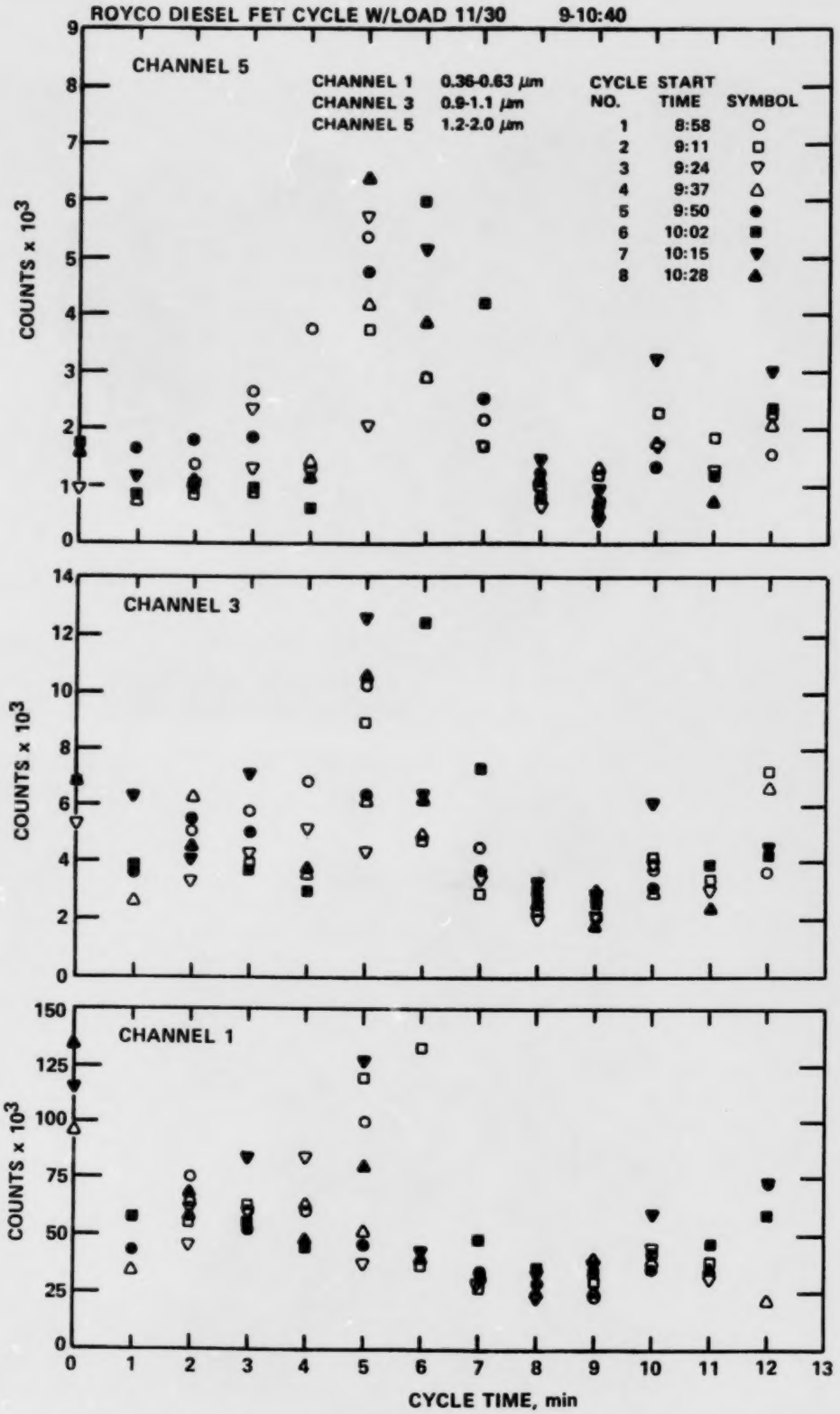

Figure 6. Relative concentration versus time for three particle size ranges during several FET cycles.

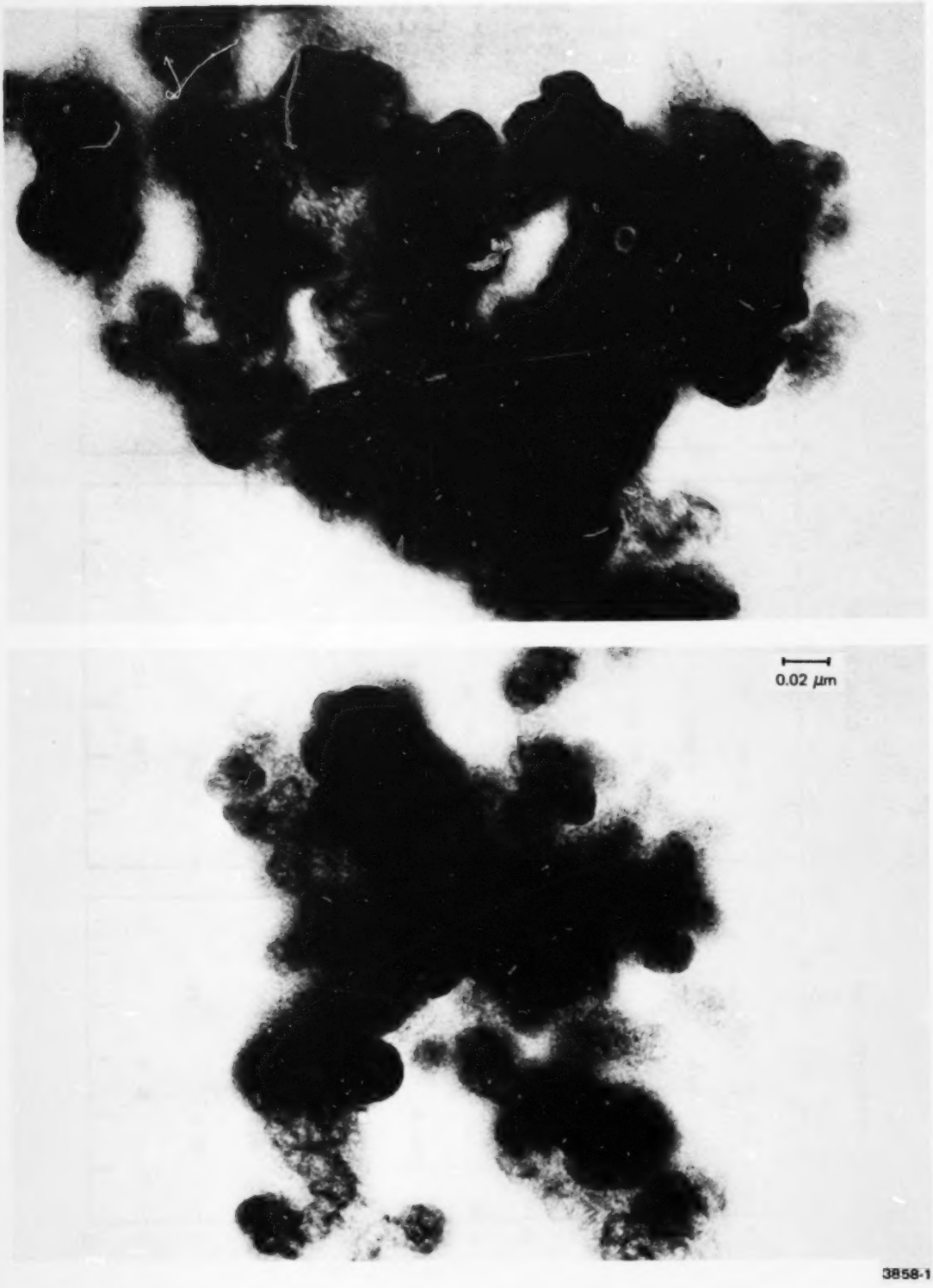

Figure 7. Electron micrograph of diesel particulate.

structure which gives rise to the low bulk density associated with diesel particulate. The very small primary particle size is also evident in Figure 7.

The particulates collected at exhaust gas temperatures were found to be approximately 15 percent by mass organics. The results of the biotesting of the samples from the impactors, filters, and organic vapor traps will be reported elsewhere.

SECTION 4

CONCLUSIONS

Typical particulate concentrations at exhaust line conditions for the Oldsmobile 350 CID diesel engine were found to be about 50 mg/NCM. Aerodynamic mass median diameters were about 0.3 to 0.5 μm with the larger median diameters being obtained from higher engine speed/load conditions under steady state operating conditions. The results reported here are qualitatively similar in size distribution to those found by other investigators in measurements of emissions from heavy duty diesel engines insofar as the impactor data are concerned.[2,3]

Additional particle size and composition data are required under conditions where the engine speed and load can be maintained at a constant value while the exhaust gas temperature is varied. This data would determine the suitability of particle collection at exhaust gas temperatures and would help define the need for cooling the collection device.

SECTION 5

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